

# The dynamics of plant productivity under controlled conditions. Diversity or information exchange?

Vladimir K Mukhomorov

Agrophysical Institute, St.-Petersburg, 195220, Russia

Correspondence: Vladimir K Mukhomorov([vmukhomorov@mail.ru](mailto:vmukhomorov@mail.ru))

**Abstract** We result statistical analysis of experimental data on physical modeling of primary soil formation under long and continuous cultivation of plants on initially abiogenous mineral substrates (granite crushed stone, zeolite). The purpose of the experiment was to follow the dynamics of the evolutionary changes in the mineral substrate under condition long-term operation. We used the information approach to quantitative analyze of the relationship of primary soil formation process with the vital activity of plants (tomato, spring wheat) under controlled conditions. We analyzed the dynamics of the diversity of emerging organic matter in the mineral substrate and the biotic community. To quantify the diversity of multicomponent systems, we used information function. We have shown that the dynamics of plant productivity was statistically significant related to the parameter of information exchange between emerging organic matter and biotic community. It has been established that the increase in the total content of organic matter in the mineral substrate does not have a statistically significant correlation with the productivity of plants.

**Keywords:** Biotic community; Cause-and-effect; Diversity; Dynamics; Information function; Mineral substrate; Organic matter; Productivity; Soil formation; Spring wheat; Tomato; Vegetation, Nitrates

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## 1. Introduction

According to the data of our experiments<sup>[1]</sup> for long-term, uninterrupted and intensive use of mineral substrate for cultivating plants under conditions of a controlled agroecosystem, mineral substrate (granite crushed stone, zeolite) undergo significant changes due to the development of the initial stages of primary pedogenesis. An important phase in this micro-evolutionary process is the formation of a group of organic components of a different nature, and biotic community which in many respects determines the main chemical, physico-chemical, and biological properties of mineral substrate. Processes of accumulation and transformation of organic matter, formation of the biotic community in mineral substrate is similar to the processes that occur in natural conditions. Assing I.A.<sup>[2]</sup> point out the important role of organic matter in weathering of minerals, elutriation of ash minerals, and their uptake by plants. Transformation of the mineral component of rocks, in Polynov's opinion<sup>[3]</sup>, is the factor which introduces the progressive element into pedogenesis. It was revealed in many investigations (see, for example, review<sup>[4]</sup>) that humic substances include cations of various chemical elements as well as phosphorus, silicon, sulfur, and chlorine, supplying plants with nutrient elements.

During lengthy, intensive, and continuous exploitation of mineral substrate under controlled agroecosystem conditions, in it develop processes analogous to natural pedogenic ones related to the transformation of abiogenic

rocks into biogenic soil-like bodies, formation of biochemically, multicomponent organic matter in mineral substrate, and development of a multispecies microbiotic community. However, under our experimental conditions the processes of forming of soil-like bodies occur headily. Already to the 15th vegetation (growth period), the enrichment by carbon of the root medium increased compared to the first vegetation about threefold. The biochemical composition of organic matter changed in during operation of mineral substrate. For example, the proportion of nonhydrolyzable residue and alkali-soluble fractions increased and the relative content of cellulose and hemicelluloses in mineral substrate decreased. Subsequent transformation of organic matter led to the formation of humic acids how for new soils.

According to the data of our investigations, biological communities forming in mineral substrate under conditions of long exploitation are characterized by a considerably more quantity of living matter per unit of specific surface compared with natural soils. On density of living matter in mineral substrate can be judged on the basis that the numbers of bacteria and fungi in soils are magnitudes of the same order, whereas the specific surface of granite crushed stone is one or two orders lower than in soil (chernozem). As it is known<sup>[5]</sup>, organic matter, interacting with minerals, participates in destruction of rock, promoting extraction of chemical elements from them, and organic matter also forms labile compounds with them.

Processes of mechanical transformation of the mineral substrate are accompanied by a considerable increase in the proportion of fine particles. Destruction of mineral

substrate leads to a substantial change in the trophic environment and noticeable variation of the chemical composition of plant and also their productivity.

The purpose of the present work was to analyze the dynamics of the plants' productivity and to reveal the cause-and-effect interrelations between the dynamics of productivity of plants and dynamics of multicomponent organic matter in mineral substrate and also dynamics of multicomponent biotic community. We shall use an information approach, the methods of which allow quantitatively determine of cause-and-effect interrelations between events as well as to indicate the direction of information flows between multicomponent systems. Use of the information approach allows to fulfil quantitative analysis of the interrelationship dynamics of diversity systems of organic matter and biotic community with the dynamics of plant productivity under condition of primary soil formation.

## 2. Method

### 2.1. Experiment

Plants of tomato (variety Ottawa-60) and spring wheat (variety Siete Cerros) were cultivated in the germinator by the method of a small-volume aggregate hydroponic under two-way adjustment of the water regime of the roots.

We used also Knop's nutrient solution. The nutrient solution was not changed during entire growth of the plants. We corrected the solution periodically. We used luminaires based on DNaT-400 sodium lamps with a solid-state heat-absorbing filter. The intensity of the radiant flux corresponded to  $100 \pm 10 \text{ W/m}^2$  in the photosynthetically active radiation region. The photoperiod has been 16 h/days with a growth length of 75 days. The plants were grown on an originally abiogenic mineral substrate (granite crushed stone) during twenty-three uninterrupted vegetation cycles and on zeolite crushed stone during the twelfth continuous vegetations. The following operations were carried out while growing of the plants. After each growth period of the plants, first- and second-order roots were removed, the mineral substrate was composted for 20-30 days, and then we were carried out by the method of regeneration (control factor) that developed in<sup>[6]</sup>. After every vegetation cycle the plant samples were taken for study of the chemical elemental composition of the different plant organs.

After each growth period, we studied the chemical composition of organic matter, which included cellulose, hemicelluloses, water- and alkali-soluble and alcohol-benzene fractions, and nonhydrolyzable residues according to the experimental scheme given in<sup>[5]</sup>. To manage plant productivity, the experimental design included a change of crops: after 12th growth period on the mineral substrate on which wheat had been grown, we began were grown tomato, and, conversely. Furthermore, we grown green manure crops instead of tomato and wheat in the 20th and 22nd growth periods.

Number of variants 1, 2, 3 and 4, 5, 6 we used for tomato and spring wheat, respectively. Check experiments are the variants 3 and 6. To reduce the total organic matter in the mineral substrate (granite crushed stone), we implemented additionally acid-base regeneration in the

experiment (variants 1 and 4). Processing is realized in the following sequence: performs composting, then treated with 0.005-0.01n  $\text{H}_2\text{SO}_4$  acid solution, then washed with water, then treated with 0.05n alkali solution, then washed with water again. Such complex effects can reduce the aging process of the mineral substrate. Additionally for variants 2 and 5 we carried out three times the regeneration of the roots of growing plants. Growing plants on the zeolite crushed stone was carried out only for the check experiments.

We monitored the dynamics of the changes in the chemical composition (percentage composition of matter) of organic matter quantity in mineral substrate, including cellulose, hemicelluloses, alkaline-soluble and alcoholbenzene fractions and nonhydrolyzed residue, as well of its water-soluble part in the nutrient solution. Simultaneously is analyzed the dynamics of the species composition and the amount of microorganisms (bacteria consuming mineral nitrogen, bacteria consuming organic nitrogen, spore-forming bacteria, cellulose-fermenting bacteria, fungi and actinomycetes) in mineral substrate.

We investigated dynamics of content of chemical elements in the composition of the ash of plant roots, reproductive organs, stems and leaves: Ca, K, P, S, Na, Si, Al, Fe, Zn, Mn, Mg, and Cl. Analysis of the elemental composition of plant ash after each growth period we made by using X-ray fluorescent analyzer A-30. Preparation of the plant samples and determination of dry matter and also percentage content of ash in plants were done according to method<sup>[7]</sup>.

### 2.2. Information approach

It is known that the traditional methods of processing experimental data – regression, correlation, variance, etc. enable revealing only the correspondence between the phenomena or objects being studied but not the cause-and-effect relation between them. Processes can be correlated but at the same time not cause-related. The information theory method using conditional informational function and conditional probabilities (i.e., the probability of occurrence of event  $X$  depends on the occurrence of event  $Y$ ) when dynamic indices make it possible to unambiguously indicate the direction of information flows into intercoupling of the multicomponent subsystems. In the literature it is noted that processes of transfer of both energy and matter and information are characteristic for soil systems. However, the quantitative measure of information transfer there is not in the literature. Calculation of unconditional and conditional information function permits quantitative assessment of the measure and direction of information transmission between coupled subsystems. Under the dependence of two events we imply the possibility of occurrence of one of the events from appearing of the other. Here we try to establish a linkage between the dynamics of plant productivity with information exchange between dynamic subsystems – organic matter and biotic community of the mineral substrate.

For a quantitative description of dynamics of multicomponent system (biochemical composition of organic matter and numerical or species compositions of the biotic community) it is convenient to use an integral index – the Shannon information function<sup>[8]</sup>. Information

theory methods allow approach to study of the temporal organization between coupled subsystems from qualitatively new positions. This approach to an analysis of experimental results belongs to the class of statistical methods of reducing the sample size and singling out the most common informative factors. Information function of the finite ensemble of objects can be written in *nat* units in the following way:

$$H = -\sum_{i=1}^n P_i \ln P_i \quad (1)$$

under additional conditions

$$0 \leq P_i \leq 1, \quad \sum_{i=1}^n P_i = 1,$$

where  $n$  is a discrete number of object-features of the set, which determine the space of possible values of  $P_i$ . Information function (1) is an integral index of the state of the multicomponent system. The values of  $P_i$  determine the share of the  $i$ th element in the entire collection of the set of elements (e.g., its percentage content or relative content of organic matter fractions of the mineral substrate), i.e.,  $P_i$  assigns the number of realizations or possible ways out. Actually, to calculate the specific number  $P_i$ , we use A.N.Kolmogorov's combinatorial approach<sup>[9]</sup> for a collection of  $n$  elements entering into this set with normalized mass  $P_i$ . Function (1) is used for a quantitative determination of the measure of organization or diversity of multicomponent subsystems. For example, the values of  $P_i$  are calculated from the data on the content (percentage) of organic matter components in mineral substrate and biotic community (percentage) for each growth period (vegetation).

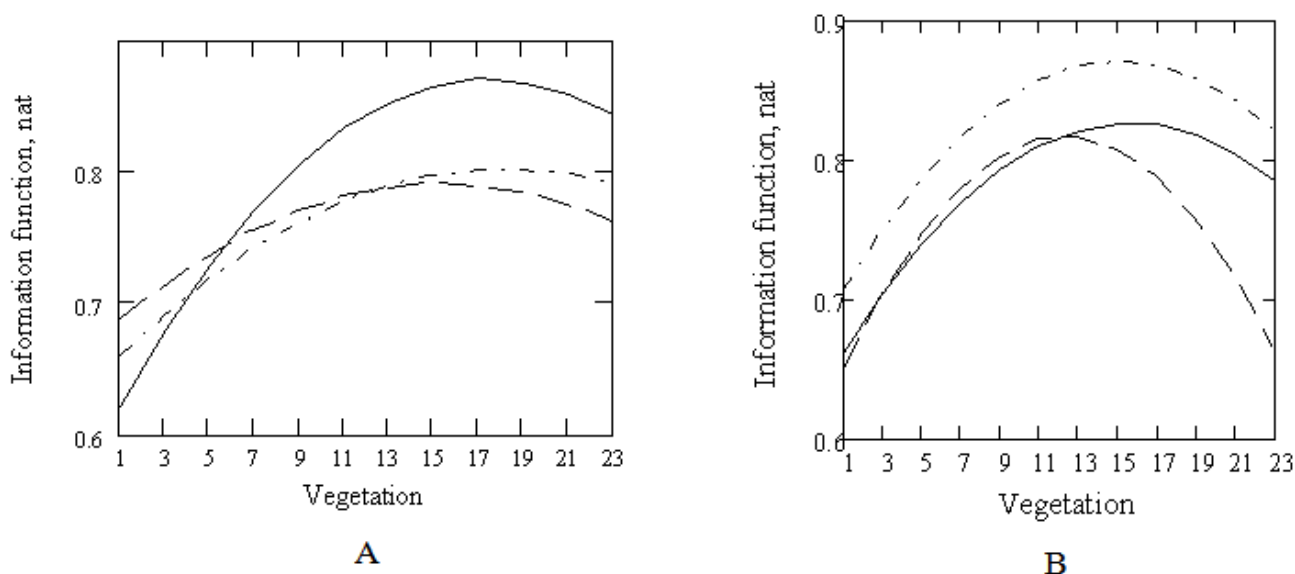
We analyzed the temporal variations of function (1) for multicomponent systems at discrete moment of times  $t = T, 2T, \dots, 23T$ , where  $T$  is the duration of one growth period. The number 23 indicates the total number of growth periods. It was established earlier<sup>[1,10]</sup> that during

intensive and long-term exploitation of mineral substrate the trophic environment changes such that the diversity (with respect to percentage content of components) of organic matter and microbiotic community forming in mineral substrate decreases. This process accompanied by an increase in the information function. (Figures. 1 and 2).

However, after crop rotation (12th growth period) the structuredness or diversity of these multicomponent systems begins to increase. This is characterized by a decrease of information function with a simultaneous increase in total organic matter content in mineral substrate.

Change of plants productivity (see below) does not match to quantitative change in diversity (information function  $H$ ) in the subsystems of the organic matter and biotic community (Figures 1 and 2). Productivity of the plants is highest possible for first growth periods for both wheat and tomato. The same vegetations are characterized by a high diversity of subsystems of organic matter and biotic complex. In the area of maximum of the information function elements of multicomponent subsystem are most uniformly distributed that corresponds to the minimum diversity. With increasing duration of exploitation of mineral substrate the diversity of subsystems decreases. At the same time reduced the productivity of plants.

However, after the crop rotation (12th vegetation) diversity of the subsystems begins to noticeably increase. This increase of the diversity was accompanied by a slight increase of plant productivity. Although a diversity of subsystems becomes even higher than for the initial vegetations the productivity of plants remains low. As it is shown by the statistical analysis, this interrelationship of the diversity and productivity has only qualitative character. This result does not allow us unambiguously to relate the dynamics of productivity of the plants with the dynamics of the diversity of the chemical composition of organic matter and the diversity of the biotic community.

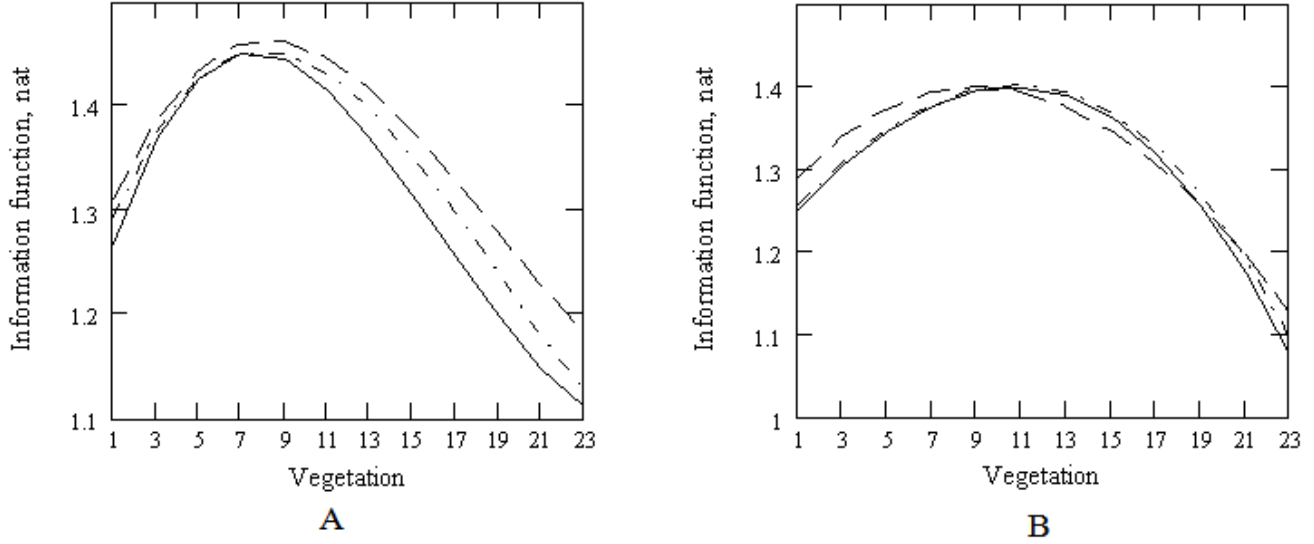


**Figure 1.** Dynamics (trend) of the information function for organic matter. Crushed granite. A – Tomato. — variant 3, --- variant 2, ··· variant 1. B – Spring wheat. — variant 6, --- variant 5, ··· variant 4.

At the same time, a monotonic increase in the content of organic matter in the rooting medium also does not explain the trend in increase of the plants productivity ranging from 19 to 23th vegetations (see below).

In this regard, we analyze quantitatively the dynamics of the exchange of information between multicomponent

subsystems: organic matter and biotic community. Methods of information theory allows us to do this by using conditional information functions. Information approach allows us to link quantify the dynamics of variability of multicomponent subsystems with the dynamics of plant productivity.



**Figure 2.** Dynamics (trend) of the information function for organic matter. Crushed granite. A – Tomato. — variant 3, --- variant 2, - · - variant 1. B – Spring wheat. — variant 6, --- variant 5, - · - variant 4

### 3. Results and Discussion

As is known, information function of a complex experiment (simultaneous realization of the events  $X$  and  $Y$ ) can be determined by the equation<sup>[11]</sup>:

$$H(X, Y; t) = - \sum_{i=1}^k \sum_{j=1}^k P(X_j, Y_i; t) \ln P(X_j, Y_i; t) \quad (2)$$

$$= H(X; t) + H_X(Y; t) = H(Y; t) + H_Y(X; t)$$

where  $H(X; t)$  is the unconditional entropy of experiment  $X$ ,  $H_Y(X; t)$  is the information function of experiment  $X$  (for example, biotic community in the mineral substrate) under the condition of performing experiment  $Y$  (for example, chemical composition of organic matter in the mineral substrate). If experiments  $X$  and  $Y$  are interrelated, the conditional information function is less than the unconditional, i.e.,  $H(Y; t) \geq H_X(Y; t)$ . Obviously, additivity of complex information function of two events  $X$  and  $Y$  is achieved in the case of their complete independence:

$$H(X, Y; t) = H(X; t) + H(Y; t) \quad (3)$$

and  $P(X, Y; t) = P(X; t)P(Y; t)$ . Function  $H(X; t)$  is an integral index of the multicomponent system at time  $t$ . This function is used for a quantitative determination of the measure of organization or diversity of multicomponent systems. Conditional information function of two random processes  $X(t)$  and  $Y(t)$  is determined as

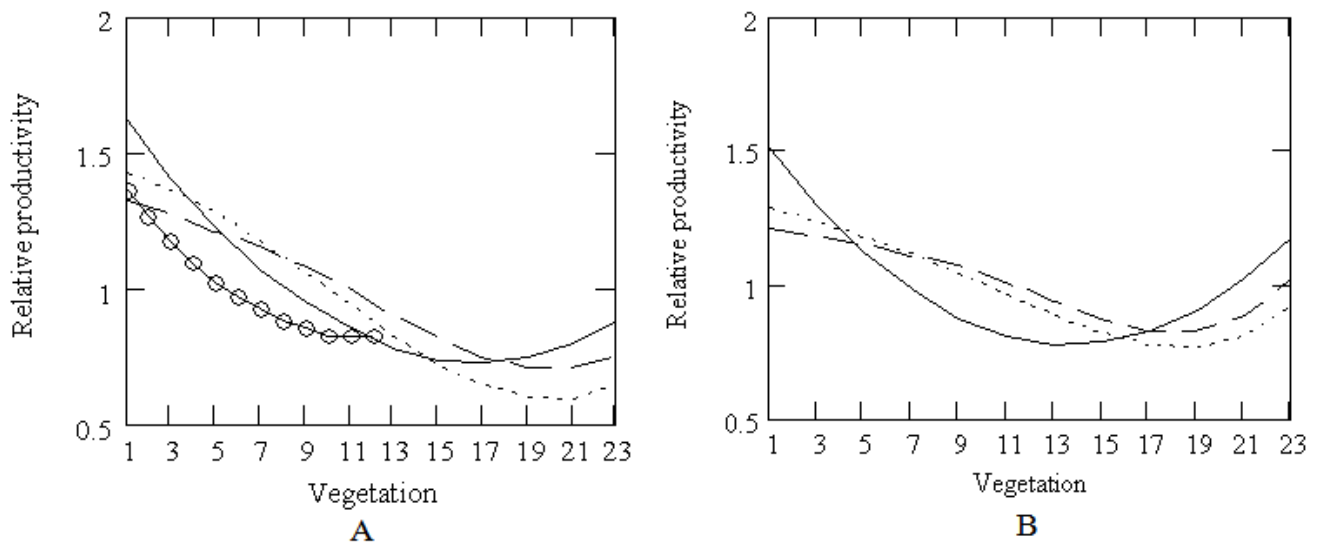
$$H_Y(X; t) = - \sum_{j=1}^n P(Y_j; t) \sum_{i=1}^k P_Y(X_i; t) \ln P_Y(X_i; t), \quad (4)$$

where  $P_Y(X_i; t)$  is the conditional probability (in terms of Kolmogorov A. N.<sup>[9]</sup>) of realizing state  $X_i$  of ensemble  $X(t)$  (effect) under the condition that state  $Y_j$  of ensemble  $Y(t)$  (cause) was realized;  $P(Y_j; t)$  is the unconditional probability of the  $j$ th level of realizing event  $Y$ . Here  $X_i(t)$  and  $Y_j(t)$  are time series corresponding to experimental values of the component compositions of the biotic community and organic matter, respectively. Probability  $P_Y(X_i; t)$  means that the information about the event  $X$  is partially contained in the event  $Y$ .

Using dynamic conditional information function and conditional proportions uniquely opens the possibility to indicate a preferred direction of information flow in the interconnected subsystems. In accordance with<sup>[10]</sup> we introduce the quantities  $I(X, Y; t) = H(Y; t) - H_X(Y; t)$ . This quantity is the information about event  $Y$ , which is contained in the event  $X$ . The same time the quantity  $I(Y, X; t) = H(X; t) - H_Y(X; t)$  is information about event  $X$  contained in event  $Y$ . If event  $X$  completely determines the outcome of event  $Y$  (maximally strong cause-and-effect relation between event  $X$  and event  $Y$ ), then information function  $H_X(Y; t) = 0$ . If information function  $H_Y(X; t) = 0$ , then event  $Y$  (for example, state of organic matter) is the cause and event  $X$  (for example, state of the biotic community) is the effect. If the difference  $H_Y(X; t) - H_X(Y; t) > 0$  then, we can speak about information flows from source  $Y$  to addressee to  $X$ . If events  $X$  and  $Y$  are independent, then obviously quantity information flow equal to zero. The smaller this quantity (positive), the greater the information flow from

subsystem *Y* to subsystem *X* and the higher the cause-and-effect relation between the interrelated processes of a change in the chemical composition of organic matter and biotic community which develop in time. Information

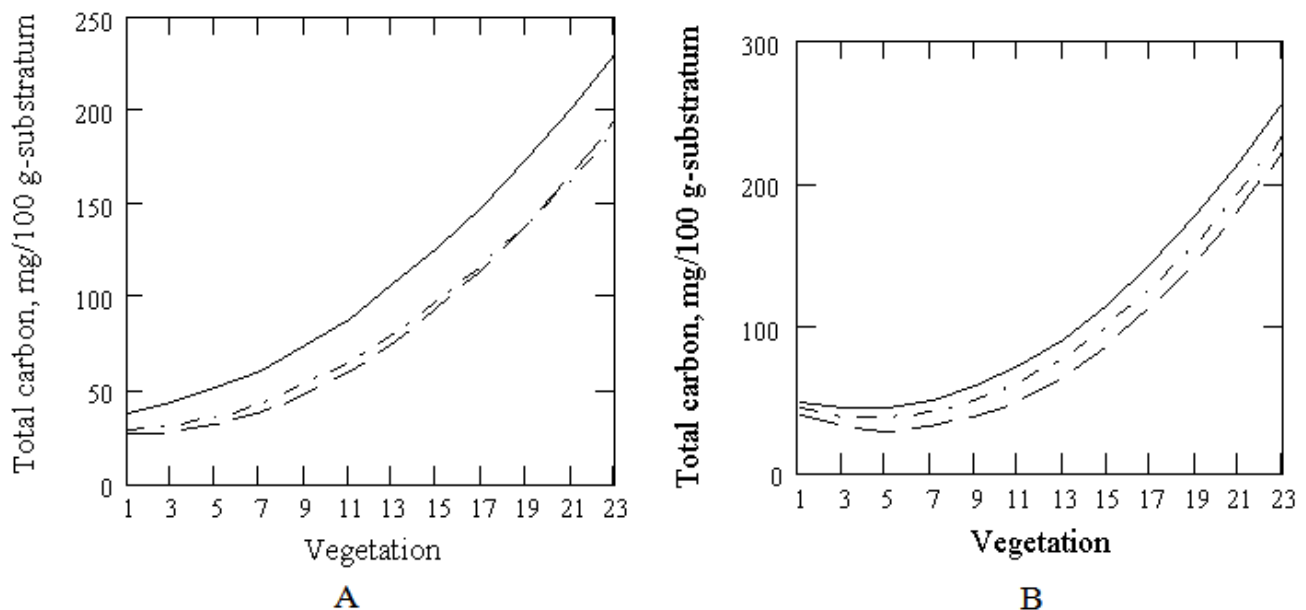
flows determine the objective content of the relation between interacting material objects manifesting itself in a change in the state of these objects.



**Figure 3.** Relative productivity (trend) of tomato plants (A) and wheat (B): — variants 3 and 6, — — variants 2 and 5, ···· variants 1 and 4. —○— tomato plants grown on zeolite

In order to be able to compare the dynamics of productivity of tomato and wheat we will use the relative productivity. Relative productivity, we have determined by

dividing the actual productivity at its average value for the entire period of observation for each variant of the experiment.



**Figure 4.** Dynamics (trend) of the total carbon in the mineral substrate. (A) Tomato, (B) wheat. — variants 3 and 6, — — variants 2 and 5, ···· variants 1 and 4, respectively

**Figure 3** shows the dynamics of relative plant productivity with respect to average productivity. For the first vegetation cycle the productivity of plants is maximum and is close to the productivity of plants grown in the black soil. However, the complex changes in the mineral substrate, which occur during long-term operation of the substrate leads to a deterioration in the quality of agro-substrate. This, in turns, is accompanied by a decrease in plant productivity. In continuous operation mineral substrate productivity both tomato and wheat decreased in all variants of the experiment. As follows

from our experiments, the intensity of the decrease in plant productivity above for granite crushed stone, compared with the zeolite.

The greatest decrease in plant productivity observed after the eleventh growth period. However, after the crop rotation (the twelfth growth period), and the cultivation of green manure (eighteenth, twentieth and twenty-second growth periods) downward trend of productivity is changed to its increase. It is well known that crop rotation improves the quality of organic matter in the roots



medium. Instead of tomato we were grown wheat, and instead of wheat was grown tomato.

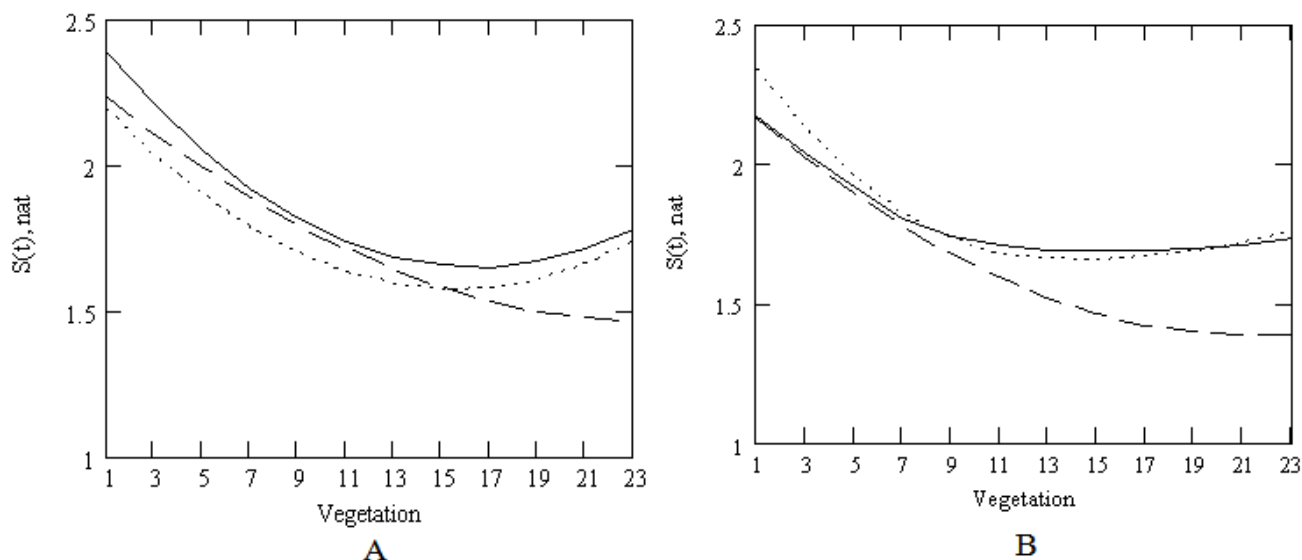
In agricultural practice, it is assumed that the productivity of plants is related to the content of organic matter in the roots medium. Our experiment shows that the progressive accumulation of organic matter in the mineral substrate does not correlate with the productivity of plants (**Figures 4A and 4B**). That is, the content of total organic matter in the mineral substrate is not the factor determining the productivity of plants.

Using both the conditional information function and conditional proportions, opens the possibility of quantitatively point the predominant direction of information flow (causal relationship) in the interconnected subsystems. A comparison of the dynamics of information functions (**Figures 1 and 2**) for organic matter and biotic community demonstrates that for last vegetation the diversity of these coupled systems is increasing, but it is not correlated with the productivity of plants. This result does not allow us to associate the dynamics of plant productivity with the dynamics of the diversity of chemical composition organic matter and biotic community in mineral substrate.

We will carry out statistical quantitative analysis of the relationship between the dynamics of plant productivity and the exchange of information between the multicomponent systems of organic matter in mineral substrate and biotic community. **Figures 5A and 5B** shows the dynamics  $S(t) = H_Y(X; t) - H_X(Y; t)$  demonstrating the nonlinear temporal dependence of the information flow from organic matter to the biotic community.

With increase in the duration of use mineral substrate, the cause-and-effect relation between these systems weakens. However, it begins to increase already by the 19th growth period. This temporal dependence of the cause-and-effect relations correlates with nonlinear dynamics of inverse productivity of plants, showing an increase of plant productivity by the 23rd growth period (**Figures 5A and 5B**).

The results don't depend on the plant species being grown or the variant of the experiment. At the same time, the experimental data on the dynamics of accumulation of organic matter indicates its statistically significant increase during the entire observation period.



**Figure 5.** Dynamics (trend) of the information exchange function tomato plants (A) and wheat (B). Granite crushed stone. — variants 3 and 6, — — variants 2 and 5, — · — · — variants 1 and 4

**Table 1** summarizes the statistical properties of deterministic mutual relations of plant productivity with the magnitude of information flows between organic matter in the mineral substrate and biotic community. Large  $t$ -values point to a close statistical connection between these factors. **Table 1** also presents the correlation coefficients, which are significantly greater than statistical tests.

Over the entire period of experimental observation the dimensionless quantity parameter  $S(t) > 0$  that is, the diffusion of information flow increasingly from a multicomponent organic matter to biotic community. The weakening of the causal linkage between these systems leads to a statistically significant reduction of plants productivity. Rotation of the crops leads to amplification of the cause-and-effect relations. Thus the exchange of information becomes a quantitative reality as well as the

exchange of energy and matter. Thus, the causal-and-effect relation between the dynamics state of organic matter forming in a mineral substrate and dynamics of the biotic community has not only scientific interest but also of practical significance and is an important information factor of the dynamics of system mineral substrate - plants related to the production potential of plants.

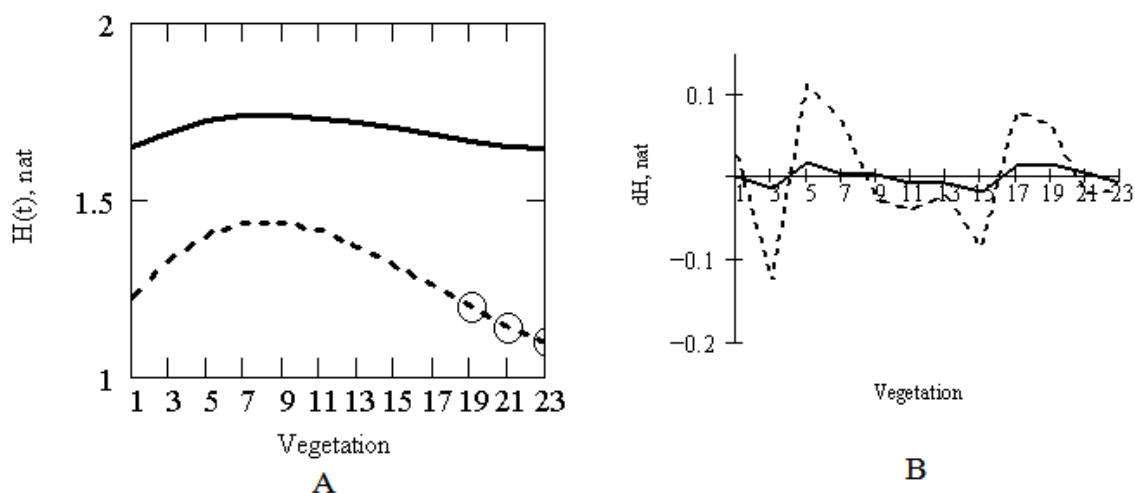
Crop rotation also affected the content of chemical elements in plants<sup>[12]</sup>. Evidently, intensive saturation of plant tissues with chemical elements is related to progressive weathering of the mineral substrate by organic matter, biotic community and vital activity of root system of plants. Evolutionary processes of primary pedogenesis are accompanied by the formation in the mineral substrate of organic matter which accelerating the rate of weathering of chemical elements from the mineral substrate.

**Table 1. Statistical characteristics of the relative plants productivity with the information parameter  $S(t)$ .  $R$  is the linear correlation coefficient, and  $R_{0.95}^{(cr)}$  is the critical test.**

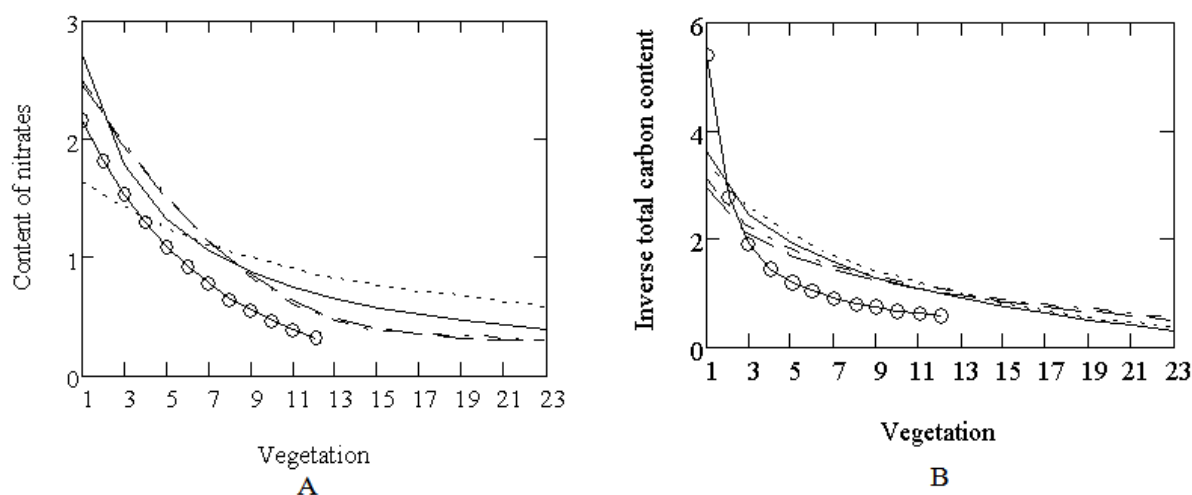
| Tomato                              |                                     |                                     |
|-------------------------------------|-------------------------------------|-------------------------------------|
| Variant 3                           | Variant 2                           | Variant 1                           |
| Student's test                      | Student's test                      | Student's test                      |
| $t = 56.3 > t_{0.95}^{(cr)} = 1.8$  | $t = 15.3 > t_{0.95}^{(cr)} = 1.8$  | $t = 56.3 > t_{0.95}^{(cr)} = 1.8$  |
| $R = 0.99 > R_{0.95}^{(cr)} = 0.53$ | $R = 0.90 > R_{0.95}^{(cr)} = 0.53$ | $R = 0.98 > R_{0.95}^{(cr)} = 0.53$ |
| Spring wheat                        |                                     |                                     |
| Variant 6                           | Variant 5                           | Variant 4                           |
| Student's test                      | Student's test                      | Student's test                      |
| $t = 10.7 > t_{0.95}^{(cr)} = 1.8$  | $t = 16.1 > t_{0.95}^{(cr)} = 1.8$  | $t = 11.2 > t_{0.95}^{(cr)} = 1.8$  |
| $R = 0.90 > R_{0.95}^{(cr)} = 0.53$ | $R = 0.91 > R_{0.95}^{(cr)} = 0.53$ | $R = 0.90 > R_{0.95}^{(cr)} = 0.53$ |

**Figure 6** shows the dynamics of information function  $H(t)$  for total organic matter in mineral substrate and dynamics of multicomponent elemental chemical composition of tomato roots.  $R^2 = 0.94$  is the coefficient of determination; Fisher's test equal to  $F = 144.8 >> F_{1.0;0.05}^{(cr)} = 5.0$ ; Student's test equal to  $t = 12.03 >$

$t_{0.95}^{(cr)} = 1.81$ . We used the statistical method for rates and proportions<sup>[13]</sup> for determination of the mutual accordance in the positions of the maxima and minima of the information function  $dH(t) = H_{\text{exp}}(t) - H_{\text{trend}}(t)$  (**Figure 6B**). We calculated the information function  $H_{\text{exp}}(t)$  using the experimental data.



**Figure 6.** Comparison of information functions for trends (A) and oscillations (B) about trend of the elemental chemical composition (—) of tomato roots and organic matter (---) in the mineral substrate (granite crushed stone) under tomato. The harmonic state of organic matter is marked by circles



**Figure 7.** A. Dynamics (trend) relative content of nitrate in tomato fruit and wheat grain. B. Y-axis — the inverse content of total carbon in the mineral substrate. — variants 3 и 6, --- variants 2 и 5, -.- variants 1 и 4. -o-o- tomato on a zeolite

The methods of information theory allow us quantitatively determine the harmonicity of a multicomponent system at a certain time  $t$ . If the value of the relative information function  $h(t) = H(t) / H_{\max}$  is close to the solution of the equation  $h(t)^2 + h(t) - 1 = 0$ , which is equal to 0.618 (this number is related to the sequence of values of the Fibonacci series), then such system is close to the state of structural optimum or structural consistency;  $H_{\max}$  corresponds to the state of a multicomponent system with equally distributed components. The harmonic states of organic matter are located in the time region after crop rotation (**Figure 6A**) and cultivation of green manure crops.

Discussing the problem of plant productivity, we analyzed the dynamics of nitrate content in plants. Experimentally is observed rising nitrate content in tomato fruits and grains of wheat for the first vegetations. However, with increasing duration of exploitation of mineral substrate nitrate content decreased (**Figure 7A**).

It is known that accumulation of nitrate in plants is closely associated with the complex of organic compounds in the root medium, which affect the vital activity of the roots and metabolism of nitrogen

compounds in plants (**Figure 7**). We can assume that the complex organic compounds are connected with nitric nitrogen in the plants<sup>[14]</sup>.

For ease of comparison of the dynamics of the total carbon content in the root medium and dynamics of nitrate nitrogen content in the reproductive organs (**Figure 7A**), we use the inverse magnitude of total carbon content (**Figure 7B**). **Figures 7A and 7B** also shows the results of an additional experiment. In this experiment, we grow tomatoes on the zeolite during the twelfth uninterrupted vegetation cycles. We found a statistically significant correlation between the inverse magnitude of the total carbon content in the mineral substrate and the content of nitrate nitrogen in plant products (**Table 2**).

**Table 2** gives statistical criteria for interrelations variants 2 and 3, as well as variants 5 and 6. An increase in the total carbon in mineral substrate correlates with the reduction of nitrate nitrogen in plants. We found that by the twenty-third of growth period the content of total carbon in the mineral substrate is increased by more than ten times. This increase is accompanied by a decrease of nitrates in tomato fruit by more than two times, and in wheat more than six times.

**Table 2. Statistical characteristics of interrelationship between of inverse content of total carbon in the mineral substrate (in unit mg/100g of the mineral substrate), and content of the nitrate nitrogen in the reproductive organs of the plants (in unit mg / kg of fruit (grains)).  $R$  is the coefficient of linear correlation**

| Tomato       |   |                                      |           |   |  |
|--------------|---|--------------------------------------|-----------|---|--|
| Variant 3    |   |                                      | Variant 2 |   |  |
| $R$          | Fisher's exact test                               | Student's test                       | $R$       | Fisher's exact test                               | Student's test                           |
| 0.998        | $F = 1185.5 >>$<br>$F_{0.95}^{(cr)}(20,20) = 2.1$ | $t = 48.7 > t_{0.95}^{(cr)} = 1.73$  | 0.999     | $F = 5905.5 >>$<br>$F_{0.95}^{(cr)}(20,20) = 2.1$ | $t = 109.1 > t_{0.95}^{(cr)} = 1.73$     |
| Spring wheat |   |                                      |           |   |  |
| Variant 6    |   |                                      | Variant 5 |   |  |
| $R$          | Fisher's exact test                               | Student's test                       | $R$       | Fisher's exact test                               | Student's test                           |
| 0.990        | $F = 180.9 >>$<br>$F_{0.95}^{(cr)}(20,20) = 2.1$  | $t = 19.02 > t_{0.95}^{(cr)} = 1.73$ | 0.986     | $F = 161.4 >>$<br>$F_{0.95}^{(cr)}(20,20) = 2.1$  | $t = 18.0 >$<br>$t_{0.95}^{(cr)} = 1.73$ |

As it is shown by our experiment the dynamical interrelationships between the content of the total carbon in the mineral substrate and content of nitrates in the reproductive organs does not depend on the botanical type of plant and used mineral substrate. It should be noted that in our experiment the nitrate content in the crop significantly below the maximum allowable concentration for plants. In our experiment is not confirmed interrelationship of plant productivity and organic matter content in the rooting medium. The experiment showed that the accumulation of total carbon in the mineral substrate does not increase the yield of plants.

## 4. Conclusion

Our experimental data demonstrate that under condition of primary soil-formation in the mineral substrate arise interrelated processes of formation of multicomponent organic matter and multispecies biotic community. Under the conditions of intensive exploitation of mineral substrates occurs biogenic and physico-chemical weathering of mineral rocks, minerals destruction, formation of fine fractions. These processes have a

significant effect on the vital functions of plants and on content of chemical elements in plant tissues<sup>[12]</sup>. With increasing duration of operation of initially abiotic mineral substrate we observed phenomena that resemble soil fatigue. Plant productivity is reduced. However, the use of crop rotation stops this negative process. Crop rotation returns the system of plants - soil to a more stable state.

The experiment showed that, although the productivity of wheat and tomato plants to 23rd vegetation increases, however, the productivity is notably lower than in the early growing season. This relationship is remained for all variants of the experiment and does not depend on the type of mineral substrate. This result does not allow us unambiguously to relate the dynamics of plants productivity with dynamics of the diversity of the biochemical composition of organic matter and biological diversity of the biotic community. At the same time, the collective state of the chemical elements in the different plant organs closely related both for starting vegetation cycle and for final growing cycle and does not correlate with plant productivity<sup>[12]</sup>.

Application of the methods of information theory have allowed us to introduce a quantitative measure that determines the flow of information between linked



multicomponent systems. As shown our study the weakening of the cause-and-effect linkage between the subsystems of organic matter and biotic community, leads to a statistically significant reduction in plant productivity. At the same time, a monotonic increase of the organic matter content in the mineral substrate also can not explain the increase in productivity in the range of 19 to 23th vegetation cycles. The use of two methods of acid-alkaline regeneration of a mineral substrate does not change the direction of the evolutionary processes of soil formation.

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